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UNITED STATES AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY
Wright-Patterson Air Force Base, Ohio

A PARAMETRIC COSTING MODEL FOR FLIGHT SIMULATOR ACQUISITION

Milton C. Ross, Captain, USAF
Gerald L. Yarger, Captain, USAF

SLSR 22-76B

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The acquisition of flight simulators has been plagued by cost growth difficulties arising from poor initial cost estimates. A parametric costing model for simulator acquisition was perceived as a tool which could provide required cost estimates early in the acquisition process. This research effort utilized multiple regression analysis to formulate a parametric costing model or cost estimating relationship (CER) for specific application to flight simulator acquisition. Data derived from existing simulator systems which pertained to system cost as well as physical and performance characteristics provided the basis for model development. A significant relationship was found to exist between cost and several system characteristics. This relationship was validated through various statistical tests and enabled model formulation. The research indicated that continuing collection and utilization of CER data would provide for further refinement of the parametric costing model.

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A PARAMETRIC COSTING MODEL FOR FLIGHT SIMULATOR ACQUISITION

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Milton C. Ross, BS
Captain, USAF

Gerald L. Yarger, BS
Captain, USAF

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ABSTRACT

The acquisition of flight simulators has been plagued by cost growth difficulties arising from poor initial cost estimates. A parametric costing model for simulator acquisition was perceived as a tool which could provide required cost estimates early in the acquisition process. This research effort utilized multiple regression analysis to formulate a parametric costing model or cost estimating relationship (CER) for specific application to flight simulator acquisition. Data derived from existing simulator systems which pertained to system cost as well as physical and performance characteristics provided the basis for model development. A significant relationship was found to exist between cost and several system characteristics. This relationship was validated through various statistical tests and enabled model formulation. The research indicated that continuing collection and utilization of CER data would provide for further refinement of the parametric costing model.

This thesis, written by

Captain Milton C. Ross

and

Captain Gerald L. Yarger

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 7 September 1976

Eugene E. Jones
COMMITTEE CHAIRMAN

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Chapter 1

BACKGROUND

STATEMENT OF THE PROBLEM

Military acquisition and use of flight simulators has been growing rapidly due to the Department of Defense (DOD) goal of reducing total military flying hours by 25 percent prior to 1980 (24:2). DOD has committed its component arms to the increased use of flight simulators. Funds allocated to simulator acquisition have increased significantly during the past three years (24:3). Simulator acquisitions have been documented which experienced both large cost overruns and system performance below specifications due to underfunding. Underfunding has resulted from inaccurate cost estimates (9:42). The flight simulator acquisition process has not utilized the valid and accepted parametric method of cost estimation (6). A tested parametric costing model (as defined later in this chapter) for flight simulator acquisition does not exist at present.

JUSTIFICATION AND DELIMITATION

The DOD flying hour reduction goal has been established due to the forecast scarcity of fuels as well as

federal budgetary constraints (24:25). To fill the gap created by reduced flying, the military services have accelerated the acquisition and employment of flight simulators and other training devices (3:7). The dramatic increase in the importance of simulators is also demonstrated by the increase in funds allocated to them. Funding to update existing training devices and initiate acquisition programs for other systems has increased from $88.5 million for fiscal year 1974 to $283 million for fiscal year 1975 (24:24). Since acquisitions of this magnitude attract great public and congressional scrutiny, it behooves acquisition managers to function as efficiently as possible. In the past this has not been the case as the following examples demonstrate.

Cost overruns have been documented on two flight simulator systems, the F-111A and the A-7E. These overruns have totalled $4.2 million to date (9:38; 3:62). During the acquisition of the F-111A simulator

> . . . cost considerations adversely affected the performance and delivery data of the final product. System performance was degraded by lack of funding and the funding provisions. System performance was degraded to the point of negative training [9:42].

As has been the experience with other recently procured DOD systems and material, the problem of cost overruns in flight simulator acquisition has evolved primarily from unrealistically low initial cost estimates as well as from changing specifications (7:3). A direct consequence of those cost overruns related to underfunding has been suboptimal system effectiveness. Less directly, cost overruns

have served to diminish public confidence in the managerial skill of its military leaders.

The need for accurate cost estimates may be overshadowed by the need for timely cost estimates. If accurate cost estimates can be furnished early in the conceptual phase of acquisition, these cost estimates will aid in several decision situations. Identifying possible cost/performance trade-offs in the design effort, providing a basis for cost-effectiveness reviews, and providing information useful in ranking known alternatives are among these recurring situations (12:6). As one researcher has noted: "Parametric Cost Estimates can provide estimates during the conceptual formulation stage of the acquisition process before detailed engineering plans are available [12:6]." The acquisition of flight simulators has been based exclusively on industrial engineering cost estimation (1:1). At this writing however an attempt is under way to validate a simulation model for the estimation of flight simulator acquisition cost (25). As has been noted previously, cost estimates for simulator acquisition have fallen short of expectations in that cost overruns/underfunding have resulted. Thus far, parametric costing procedures have not been utilized in the acquisition of flight simulators (1:2).

The traditional industrial engineering approach to cost estimating relies on detailed cost analysis of human and material input to the system under development. The parametric costing procedure utilizes historical cost data

derived from existing similar systems. The industrial engineering approach fails to account for engineering and design specification changes and other items that are not identifiable at the time of design (7:6). Because the parametric estimating procedure can account for unforeseen difficulties prior to their occurrence during development, it is by far the preferred procedure for cost estimation early in the acquisition process. As the system becomes more clearly defined the industrial engineering approach becomes increasingly accurate. At some undetermined and variable point in the acquisition process the utility of the industrial engineering approach will exceed the utility of the parametric approach due to the greater accuracy of the industrial engineering estimate (21:3).

In summary, the continual evaluation of aerospace systems provides a serious challenge to USAF acquisition managers. This challenge pertains not only to primary flight systems but also to associated flight system simulators. The absence of accurate initial cost estimates is central to this problem. Creation of a method to provide accurate cost estimates early in the acquisition cycle would significantly aid USAF managers. Captain James H. Coile, Plans and Programs Officer, Systems Program Office (SPO) for USAF Flight Simulator Acquisition, has specifically recommended research in simulator cost estimation due to his conviction that the simulator acquisition program would benefit greatly from such input (6).

Flight Simulator Technology

The technology of the nineteen-seventies has enabled flight simulators to duplicate all flight performance characteristics and yield an accurate visual representation of flight (22:29). Simulator systems which fully duplicate aircraft characteristics and provide real three dimensional motion are currently under development and production. Through complex hydraulic systems, modern simulators are able to provide the physical sensations of flight including positive and negative gravitational forces (17:40). In addition, the current generation of digital computers, which are the heart and brain of modern flight simulators, are capable of processing 2.5 million instructions per second. Technical sophistication, through computer and television application, has evolved to the level wherein several individual simulators can be linked to allow simulation of air-to-air combat among pilots occupying separate simulator stations (14:78).

The rapid increase of flight simulator technological sophistication has logically generated rapid growth in costs. The current generation of flight simulators has become as expensive to acquire as the aircraft they are designed to simulate (18:16). Therefore, flight simulator acquisition requires careful planning and close, sensitive attention to cost factors.

No research has been documented which addresses the identification of those cost factors which most

significantly affect total system cost (6). Certain factors are postulated by experts to relate most directly to total system cost. These factors include: unit weight, electrical power consumption, computer core capacity, computer instruction processing speed, the number of crew stations, the number of motion axes, system cooling capacity, the number of emergency situations simulated and the total number of sensory cues (6).

Cost Analysis Procedures

Cost analysis is an integral part of the acquisition process and is a function in which every procurement activity must engage. General George S. Brown, USAF, (5:9) has pointed to the significance of the cost analysis process and specifically to the origination of accurate and credible cost estimates. Recent trends in DOD management policy reflect the importance of the cost analysis function. The establishment of the Cost Analysis Improvement Group (CAIG) in 1972 and the recent distribution of Air Force Regulation 173-2, USAF CER/Cost Factors Program, are evidence of the importance placed on cost analysis by the DOD (7:8; 19:25).

Early in 1970 the Assistant Secretary of Defense for Systems Analysis distributed a memorandum clarifying the department's position on techniques to be used in estimating the cost of new weapons acquisition. Cost estimates were to be derived either from detailed "grass roots" calculations (the industrial engineering method) or based upon relationships between aggregate components of system cost and the

physical and/or performance characteristics of the system. These relationships were to be derived from the cost histories of prior programs. The latter of these two accepted procedures is based upon the parametric method (7:2).

To assess the advantages and disadvantages of the parametric approach to cost estimation, it is first necessary to discuss industrial engineering cost estimating procedures. Contrasting these two established procedures thereby provides the framework for understanding their respective applications.

The industrial engineering method. In the past, the defense system cost estimates reviewed by the Defense System Acquisition Review Council (DSARC) have most frequently been based on contractor estimates which, in turn, relied almost exclusively on the industrial engineering, or traditional, estimating approach (21:3). This approach is also termed the "grass roots" approach because it is founded in the exercise of gathering all the costs associated with those elements which combine to form a final product. The summation of these costs, which are located at the "grass roots" of the design, development and production processes, provides the sought-after cost estimate (21:3).

Certain facts must be known to derive a cost estimate utilizing the industrial engineering approach. Generally, the costs associated with all the labor, material and overhead which contribute to the final product must be

available in a form such that total costs can be calculated based on estimates of the input variables. The industrial engineering cost estimate, then, is a function of known or predetermined costs of the production input variables (11:5).

Due to its reliance on extensive system descriptions and design along with standards built from time and motion studies, vendor quotes and so forth, the industrial engineering approach is both cumbersome and expensive to use (11:4). Because the level of detail required in the industrial engineering approach is great, the time which must be devoted to analysis of those details is also great. Therefore, expense and time consumption detract from the effectiveness of the industrial engineering approach (7:26). Perhaps the greatest limitation of the industrial engineering approach is that it has little or no utility under conditions of: poor or incomplete system definition, rapid and frequent changes in the technological aspects of the system, or changing of the required operational capabilities (7:26).

The major strength of the industrial engineering method is the accuracy of the estimate it provides (7:26). However, to be accurate this method must have access to specific information and the information, or data, must accurately depict all the factors which contribute to total system cost. Reliance on data is, of course, at the heart of any cost estimating procedure. Former Assistant Secretary of Defense for Systems Analysis, Dr. Alain Enthover,

has noted that successful cost analysis is characterized by good data, good people, good techniques and prompt response. He further notes that, ". . . without good data, all the people, techniques and speed are useless to the analytical effort [2:24]."

The parametric method. Parametric estimates predict costs by means of explanatory variables such as performance characteristics, physical characteristics and/or characteristics relevant to the development process (e.g., milestones) which are derived from experience on related systems (12:2). These relationships are in the form of empirical formulas that relate some characteristic of the system to the cost of the same characteristic in a previously acquired and related system. Accordingly, parametric estimates reflect delays, mistakes and changing requirements based upon actual past performance (21:3).

The parametric approach can be faulted on several counts as can the industrial engineering method. The major difficulties arising from the parametric approach to cost estimation are:

1. The system for which the estimate is being made must be closely related to the system used in the data base to define the relationship, and it must be assumed that the defined relationship is still valid (12:4).

2. Accuracy of the cost estimate is limited by the fact that physical and performance characteristics

do not represent all of the reasons for variance in cost (10:9).

3. When extrapolating beyond the values of data in the data base, confidence in the accuracy of the estimate decreases (12:56).

4. The historical data needed to define the cost estimating relationship (CER) may be either expensive to obtain or nonexistent (7:26).

These deficiencies in the parametric approach are not universal; they apply only to isolated situations. These situations are all related to the nonavailability or inappropriateness of the data on which they rest. However, many situations are quite amenable to parametric application.

Assuming adequacy of data, the parametric method's strengths are:

1. Usage of actual past experience as a data base incorporates setbacks such as engineering and design specification changes that are not identifiable at the time of design (12:6).

2. Cost estimation is possible early in the conceptual stage prior to the completion of detailed engineering plans (12:6).

3. Cost estimates can be made quickly and inexpensively once the relationship has been defined (7:26).

4. The cost estimate is independent of estimator bias and, hence, more likely to be objective (7:26).

These strengths of the parametric method do not prove it to be the superior method for cost estimation. However, recent experience at the DSARC level of review has shown that the parametric estimates submitted by the CAIG have been more accurate than the industrial engineering estimates provided by the services (7:8).

The parametric and industrial engineering methods are most effective when applied simultaneously in the acquisition process since the strengths of each offset the weaknesses of the other (12:6). Currently, however, no parametric cost estimation model exists for flight simulator acquisition.

OBJECTIVES

The primary objective of this research was to formulate a parametric cost estimating model for specific use in flight simulator acquisition. Such a model was to provide cost estimates throughout the acquisition cycle but was to be based upon characteristics that are established early in the conceptual stage of acquisition. In order to substantiate the strength of the model two additional objectives were pursued. First, the model was tested to ascertain its accuracy as a predictor of actual first unit cost of a flight simulator system. Second, the model was assessed in regard to its usefulness as a cost estimation tool.

RESEARCH HYPOTHESIS

There is some combination of the following flight simulator characteristics which have a significant relationship to simulator first unit cost. The characteristics, all of which can be identified in the conceptual stage of the weapon acquisition process, are:

1. computer core capacity
2. computer instruction processing speed
3. the number of crew stations
4. motion axes
5. emergency procedure capability
6. sensory cues
7. unit weight
8. rate of electrical power consumption.

Chapter 2

METHODOLOGY

OVERVIEW OF THE DATA PRODUCING SITUATION

The data of concern in this statistical model building research were described by two general definitions. Data which represented first unit cost of various flight simulator systems was one of the classifications. The other classification consisted of those physical characteristics of the flight simulator systems which were believed to be related to first unit costs. Examination of all flight simulator systems was neither feasible nor meaningful. A representative population of the current generation of flight simulators was utilized.

Population

The population of interest consisted of USAF flight simulators in operational use during 1975. Included among those were systems which simulated transport, bomber, trainer, fighter and special use aircraft. Those systems provided the data for the cost model development.

Term Definition

1. First Unit Cost - This was the cost in adjusted dollars paid by the USAF for the first operationally installed unit of flight simulator systems.

2. Computer Core Capacity - The maximum characters which could be stored in memory.

3. Computer Instruction Processing Speed - The internal speed of transmitting information to and/or from memory. Speed was measured in microseconds (10^{-3} seconds).

4. Number of Crew Stations - The number of physical locations in the simulator system which could be manned by flight crew members.

5. Degrees of Freedom - The number of motion axes or motion planes available.

6. Sensory Cues - The number of general flight or aircraft sensations which could be perceived through either sight, hearing or sense of touch.

7. Weight - The weight, in pounds, of the simulator crew station including motion platform.

8. Rate of Power Consumption - Kilowatts of electricity/hour required to maintain normal simulator operation.

9. Emergency Procedures - The total number of emergency procedures and malfunctions simulatable.

10. Cooling Capacity - The cooling capacity required for one mission simulator expressed in BTU/hr.

Data and Data Sources

It was initially assumed that the data specifying total system costs and describing simulator system

characteristics was recorded in the various individual flight simulator contract files (6). Examination of the files was to have permitted extraction of those data values which were the foundation for the model development. The data values which were used in the model development process were ungrouped in an effort to achieve maximum accuracy.

Several assumptions concerning the data required explication.

1. Even though the individual flight simulators simulate dissimilar aircraft, the systems themselves were comprised of homogeneous features and characteristics.

2. Acquisition difficulties encountered on the systems within the data base were characteristic of difficulties encountered in the total simulator acquisition experience.

3. Contractor profit on the various systems fell within established DOD limits.

4. The system characteristics from the data base will also exist in simulator systems acquired in the future.

5. The necessary data was recorded accurately on the source documents.

Price Level Adjustment

To remove the effects of monetary inflation from the development of the model all total system costs/prices were

adjusted. The Secretary of Defense Economic Escalation Index was the basis for this adjustment (23). The base year (Index value of 100) utilized was 1975. All price figures utilized in model development were expressed in terms of 1975 constant dollars.

GENERAL MODEL FORMULATION

General Considerations

There are numerous statistical and non-statistical frameworks available for model development. Considerations as to the intended model use, data features and analysis capacity available to the researcher influenced framework selection. In this research the suspected relationship of cost to simulator system characteristics pointed toward a commonly used framework.

Regression analysis has been a proven and accepted statistical procedure. Prediction capability was one of the inherent traits of regression analysis. This research intended to develop a model to facilitate prediction of price when certain system characteristics were known. The system characteristics became predictors of total system cost when they were input to the regression analysis procedure. Least squares estimation has been the most commonly used method of regression analysis (12:35). The least squares method provided the best linear unbiased estimator (8:1) and was the framework for the development of this

parametric pricing model. Certain assumptions underlie the regression method and are enumerated here for clarity.

Assumptions

1. A linear model of the general form

$$Y = B_0 + B_1X_1 + B_2X_2 + \ldots + B_{P-1}X_{P-1} + E$$

was most appropriate for this research due to the expected relationship among the variables involved. In this general model Y was the dependent variable (cost), the X_i's were independent variables (characteristics), the B_i's were the unknown values to be determined (parameters) and E was the error term.

2. The expected value of cumulative error term (E) was zero.

3. All of the individual error terms had a constant and equal variance.

4. The error terms were statistically independent.

5. The values of the error terms were normally distributed.

6. The number of observations exceeded the number of parameters to be estimated.

7. The values of the independent variables were independent of each other.

8. The values of the independent variables were observed without significant error (8:1-3).

Computer Subprogram Utilization

Although the regression method was amenable to manual solution, it became extremely cumbersome when more than two variables were considered. Since the cost of a flight simulator appeared to be dependent on numerous variables, regression analysis utilizing digital computer support was required. The Statistical Package for the Social Sciences (SPSS) subprogram, Stepwise Multiple Regression, was utilized.

Stepwise Multiple Regression was based on a common method of solving the system of linear equations in multiple regression, that is, Gauss-Jordan elimination. The computational method provided the information necessary to select the next variable brought into the equation. The subprogram selection of variables occurred such that the model provided the best possible fit to the data observations. After all variables had been evaluated by the subprogram, an optimal model was determined which may, or may not, have included all of the variables. Variables appearing in the final form of the model were those selected by the subprogram as having actual significance. The subprogram also calculated the parameters associated with independent variables included in the model (4:180).

Model Development Procedures

Once data had been collected it was briefly analyzed with respect to range of values. The data was then supplied to the stepwise subprogram in order of smallest range of characteristic values to greatest range of values.

Characteristics which proved not to be statistically significant were eliminated from the model, and the model was developed using the remaining variables. This build-test sequence was repeated until all potential combinations had been attempted. When the subprogram had considered all available data values the resulting equation provided the best possible linear model for estimating flight simulator cost. The model was, of course, limited by the accuracy and quantity of data.

Model development was not complete until the model was assessed as to its validity. Both internal and external tests were performed on the model to determine the degree to which the model predicted cost accurately.

PROPOSED MODEL VALIDATION

Statistical Tests

Multiple R test. The proportion of total variation about first unit simulator cost explained by the regression (commonly known as R^2) had to be significant. Significance of R^2 was arbitrarily defined to be 0.70, a value perceived to be significant from inspection of R tables (15:514). It was hoped that the R^2 of the model would approach 1.0 as a limit but any value for R^2 greater than 0.70 was acceptable for the purpose of establishing validity (26:342).

F test on the overall equation. The overall statistical significance of the model was assessed by an F test.

For the purpose of this element of validation a 90% confidence level was established. If the computed F-ratio exceeded the critical (table value) F-ratio at this confidence level, the overall model was considered statistically significant (26:340).

Student's "t" test on the parameters. The parameters were assessed individually with "t" tests at the 90% confidence level to determine their individual statistical significances. Computed "t" values were compared with critical (table) "t" values in this assessment (26:298).

Standard error of the estimate. A measure of how well the model fit the data was provided by the standard error of the estimate. The standard error of the estimate computed from the model should have been relatively low in comparison to the standard deviation of the first unit simulator cost data. In addition, the distribution of the error terms for each data point should have been randomly scattered about the estimate of the dependent variable. If this situation was observed in the output of the stepwise subprogram, then a normal distribution of error terms could be inferred (20: 564-565).

External Tests

Two systems and their associated cost and characteristic data were to have been chosen to be excluded from the data base used to develop the model. Exclusion of these systems would permit testing of the model's predictive

accuracy on them. That is, data from the selected systems was to be supplied to the model and the predicted first unit costs were to be compared to the actual first unit costs of these separate systems. To be considered valid as a predictor of cost the model estimate, plus or minus one standard error, should have included the actual cost value. In addition to this straightforward and exacting criteria, one further analysis of the model was to contribute to its validation.

Internal Tests

The independent variables were carefully scrutinized to insure that they were logically related to the dependent variable. That is, if the relationship of the independent and dependent variables appeared illogical, the independent variable was excluded from the model. An example of this type of illogical relationship would have been an independent variable which should have caused cost to increase but, in fact, indicated a cost decrease. If the reason for the illogical relationship could be explained, the independent variable was included, but if explanation was not possible, it was excluded (13:340-341). This subjective criteria also contributed to model validity.

Consistency to the development process further enhanced the model's validity. As previously noted, statistical tests on the model and its parameters all utilized the same level of significance. All independent variables

received the same treatment throughout model development and only one computer subprogram was utilized in evaluating the potential contributions of the independent variables to the model.

MEETING THE RESEARCH OBJECTIVE

The research hypothesis was considered to be supported if the model met the criteria defined in the preceding paragraphs which detailed the various statistical, external and internal tests.

Chapter 3

THE DATA BASE

SOURCES OF DATA

There was no central repository for the data upon which this research depended. It was assumed that contract files would contain all required data elements, but it was discovered that these files were either inaccessible or incomplete. It was further learned that many of the physical and performance characteristic data elements did not appear in the contract files. Other data sources had to be sought and were discovered through various inquiries.

A large portion of the technical data (physical and performance characteristics) was provided by personnel of the Air Force Logistics Command (AFLC) at Ogden Air Logistics Center (ALC), Utah. The Flight Simulator and Training Aids Branch of Ogden ALC provided all technical data for those flight simulator systems which AFLC maintains. Those included the following systems: C-5A, C-141A, F-111A, FB-111A, HH-53 and A-7D. The cost data for these particular systems was extracted from active and inactive contract files maintained by the Aeronautical Systems Division of Air Force Systems Command at Wright-Patterson AFB, Ohio.

The remaining systems in the data base were the F-15, T-37B, T-38A and the Advanced Simulator for Undergraduate Pilot Training (ASUPT). All cost and technical data pertaining to the F-15 flight simulator was originated by ASD personnel assigned to the F-15 Systems Program Office (SPO) at Wright-Patterson AFB, Ohio. All data pertaining to the T-37B and T-38A systems was originated by ASD personnel assigned to the Simulator SPO at Wright-Patterson AFB, Ohio. Data pertaining to the ASUPT was provided by ASD personnel assigned to the Human Resources Laboratory (HRL) at Wright-Patterson AFB, Ohio. Approximately twenty (20) separate individuals from the above listed offices responded to this research endeavor with data input.

DATA COLLECTION METHODS

All data relevant to this research was collected and recorded manually. Numerous letters, telephone conversations and personal interviews were utilized to collect the data. The data collection process spanned an eight-month period. It was estimated that for every source which provided some portion of useful data, at least seven additional non-productive sources were contacted during data collection efforts.

INDIVIDUAL DATA POINTS

Cost and technical data was collected on eleven different flight simulator systems. Of these eleven systems,

two C-141A systems were included since the two systems were designed and produced by separate independent contractors. Although some similarity was observed in the two C-141A systems, the data indicated that the systems were essentially different. Both the F-111A and FB-111A systems were included in the data field since the differences in these two systems exceeded the similarities. For each of these eleven systems data on the dependent variable, cost, and nine independent variables, physical and performance characteristics, was collected. The technical data is arrayed and presented in matrix form in Table 1. For a detailed description of the data elements the reader should refer to Chapter 2. The cost data, which includes first unit cost, year procured, index factor and adjusted cost, is similarly arrayed and presented in matrix form in Table 2.

The Secretary of Defense Economic Escalation Index, which was used to determine adjusted first unit cost figures, was determined to be the best index available due to its wide application in DOD cost analysis. The reader is cautioned that all figures pertaining to cost are expressed in constant 1975 dollars and that the utilization of any CER in this text will require adjustment from 1975 to present or future dollars using the escalation index.

Table 1

Performance Characteristic Data

System	Computer Core	Computer Speed (Micro-Sec)	Crew Station	DOF*	EPS*	CUES	KVA	Weight*	BTU*
F-15	103K	.75	1	6	125	5	195	2,900	195,310
F-111A	8.2K	1.3	2	5	222	4	105	3,400	150,000
C-5A	44K	1.75	4	3	575	4	225	16,000	61,100
C-141A	48K	6.4	3	3	350	3	30	7,200	60,000
A-7D	48K	.6	1	4	85	5	232	35,000	250,000
HH-53	65K	1.0	3	6	175	3	100	6,000	14,910
FB-111A	131K	2.76	2	5	243	4	120	3,470	200,000
C-141A	44K	1.75	3	3	350	3	60	7,200	138,000

* Characteristics Appearing in the Final CER

Table 2

Cost Data

System	Actual Cost	Year Purchased	Index (1975=100)	Adjusted Cost
F-15	$9,740,387.00	1976	.9259	$9,018,876.88
F-111A	6,831,625.00	1969	1.5152	10,350,946.97
C-5A	7,941,047.00	1967	1.6077	12,766,956.59
C-141A	1,964,608.00	1962	1.7241	3,387,255.17
A-7D	10,852,484.00	1969	1.5152	16,443,157.58
HH-53	3,150,286.00	1971	1.3680	4,309,556.77
FB-111A	8,820,000.00	1969	1.5152	13,363,636.36
C-141A	1,627,443.50	1963	1.7212	2,801,107.57

DATA FEATURES

Strengths

The data was perceived to possess strength for the following reasons:

1. There appeared to be no bias on the part of those who provided data to the research.
2. Numerous separate sources cross-validated major portions of the data.
3. All data was expressed in quantified terms.
4. Where numerical conversions of data was necessary (e.g. nanoseconds to microseconds, tons of cooling capacity to BTU/hr.) established scientific conversion factors were available and were applied consistently.

Weaknesses

Certain weaknesses in the accumulated data were perceived and are expressed below:

1. For some data points different sources conflicted as to specific data values (e.g. three different cost figures for the C-5A, all validated and documented; different KVA ratings and cooling capacity ratings for the same system).
2. Some cost figures were more "mature" than others. The research recognized that a gap of several years can exist between acceptance of a

flight simulator and final determination of its actual cost after audit.

3. Different data sources applied unique definitions to the data they provided (e.g. crew station weight may or may not have included the weight of the motion platform).

Overall, the strengths of the data outweighed the weaknesses and the effects of some of those perceived weaknesses were removed as the data was utilized in model development as discussed in Chapter 4.

Difficulties

There was no central or common source of data. The research effort was bounded by both time and data collection method. It was noted that no CER existed for flight simulator acquisition only because there was no data from which a CER could be originated (1:1). This research endeavor found data gathering to be both the most demanding and time-consuming task. The endeavor further determined that data did exist in dispersed locations, but bringing it together through manual means was a most inefficient operation. Data in much greater detail was determined to exist in the records of flight simulator contractors, but contact with these various contractors was beyond the scope of this research due to time constraints and lack of clearance authority.

Summary

The development of any CER is bounded by data availability. Data pertaining to flight simulator systems existed but was most difficult to assemble. The data which was assembled possessed inherent strengths and weaknesses which influenced the predictive power of the CER it supported.

Chapter 4

PARAMETRIC COSTING MODEL DEVELOPMENT

Of the total array of data collected during the research effort, three systems (i.e., ASUPT, T-37, T-38) were excluded from the CER development process. The ASUPT system was found to be vastly dissimilar to the other flight simulator systems due to its unique mission and design. The ASUPT was a single system procurement and was designed for contribution to research rather than direct support of operational flying. The T-37 and T-38 Instrument Flight Simulators (IFS), as well as the ASUPT, were configured as a complex of cockpits rather than single crew stations. The cockpit complexes of the IFS system shared common motion and visual system equipment. These facts, coupled with other minor dissimilarities, made it difficult to separate the components of these three systems into configurations similar to other systems in the data base. These three systems were therefore excluded from CER/model development since their potential positive contribution as additional points in the data base was outweighed by their lack of similarity to the other systems in the data base. The data base used for CER development therefore consisted of eight separate flight simulator systems.

INITIAL ITERATION

All data pertaining to the F-15, F-111A, FB-111A, C-5A, both C-141's, HH-53A and A-7D systems was supplied to the Stepwise Multiple Regression Subprogram. The resultant equation included six independent variables. Three independent variables were excluded by the subprogram since their contributions to explained variation were not significant. Listed below are the independent variables as they were perceived on the initial iteration.

Variables Included

Variables	Parameter	"t" Value
Sensory Cues	23,830,744	3.934
Weight	738	4.055
Crew Positions	18,324,282	4.367
BTU (Cooling Cap.)	82	3.965
Deg. of Freedom	6,658,466	4.045
KVA (Elec. Power Consump.)	- 199,082	3.343
Constant (B_o)	147,870,539	---

Overall F Value = 13.46 $\quad$ R^2 Value = 98.78%

F Critical = 58.2 $\quad$ "t" Critical = 6.314

Variables Excluded

Computer Core Capacity

Computer Processing Speed

Emergency Procedures Simulatable

The R^2 factor (percentage of variation explained by the included independent variables) for the above model was 98.78%, an extremely high value and far in excess of the 70% value established as the R^2 criteria. However, the critical F statistic table value required for statistical significance for the above equation (with appropriate statistical degrees of freedom) was 58.2. The F value associated with the six variable model was only 13.46. The critical value of the "t" statistic (table value) for all variables in the model was 6.314. The preceding "t" and F values associated with the derived model all failed to exceed their corresponding table values at the 90% confidence level. This situation was due primarily to the relatively low number of data points (systems), which severely limited statistical degrees of freedom and, hence, necessitated meeting very large F and "t" critical values. The overall model and the individual parameters failed to demonstrate statistical significance even though the R^2 for the model was exceptionally high. Since the model derived on the initial iteration failed to meet statistical criteria further analysis of the data was performed.

SECONDARY DATA ANALYSIS

The potential existence of collinearity between independent variable data was perceived. Collinearity between two variables, or multicollinearity among several variables, serves to weaken data from a statistical

standpoint. That is, variables which vary in a similar manner tend to mutually reduce their individual influence on the predictive power of their combined representation. Therefore, a correlation analysis was performed on the data through use of a SPSS subroutine feature. It was discovered that three of the nine independent variables were highly correlated to a majority of the other variables. These three variables which exhibited strong multicollinearity were:

Crew Position

Sensory Cues

KVA (Electrical Power Consumption)

Therefore, each of the three above named variables was excluded from the model development process. They were excluded singly on three separate iterations so that overall changes could be noted and assessed. It was discovered that all three variables required exclusion to adequately reduce the effect of multicollinearity within the independent variable data. With the remaining data, representing six variables, further iteration was performed.

ACTUAL MODEL VALIDATION

Statistical Tests

A total of eight separate systems with data detailing the dependent variable, cost, and six independent variables detailing physical and performance features comprised the data base for the refined CER development. The stepwise subprogram provided the following model information:

Variables	Parameter	"t" Value
BTU (Cooling Cap.)	70	3.8601
Weight	504	3.9484
Deg. of Freedom	7,055,290	3.4132
Emerg. Proc.	50,623	3.7054
Comp. Speed	1,470,072	1.8358
Comp. Core	- 36,452	1.1446
Constant (B_O)	- 50, 529,969	

Overall F Value = 5.85 $\quad$ R^2 Value = 97.23%

F Critical = 58.2 $\quad$ "t" Critical = 6.314

The overall model F value failed to exceed the critical value for F at the 90% confidence level. None of the "t" values for the individual parameters exceeded "t" critical. Therefore, this particular form of the model failed to meet the statistical criteria and was therefore deemed unsatisfactory as a CER.

Since the form of the model based on six parameters was not statistically adequate, the model form based on five parameters was considered. Below are listed the salient features of the five parameter model.

Variable	Parameter	"t" Value
BTU (Cooling Cap.)	58	3.6688
Weight	475	3.5313
Deg. of Freedom	5,637,063	3.1654
Emerg. Proc.	43,187	3.3407
Comp. Speed	995,890	1.3491
Constant (B_o)	- 41,701,176	

Overall F Value = 5.84 R^2 Value = 93.59%

F Critical = 9.29 "t" Critical = 2.92

The overall F value for the five parameter model failed to exceed the critical F value but the difference was much less than was observed in the six parameter model. The individual "t" statistics for the first four parameters were significant while only the last parameter, computer processing speed, failed in the test of significance. A reduction in the R^2 value was noted in comparison to the six parameter model as might have been expected. These results were described as being typical during the discussion of the multiple linear regression technique in Chapter 2. The five parameter model partially passed the statistical test criteria and indicated an assessment of a four parameter model would demonstrate further refinement.

The four parameter model met all relevant statistical test criteria as the following table indicates.

Variable	Parameter	"t" Value
BTU (Cooling Cap.)	50	3.0223
Weight	369	2.9938
Deg. of Freedom	4,003,544	2.7157
Emerg. Proc.	35,232	2.7126
Constant (B_o)	- 28,274,648	

Overall F Value = 5.38 R^2 Value = 87.76%

F Critical = 5.34 "t" Critical = 2.35

The R^2 value of 87.76% exceeded the criteria value of 70%. The F value of 5.38 exceeded the critical F value of 5.34 at 90% confidence level. All "t" values exceeded the "t" critical value of 2.35 at 90% confidence level. The four parameter model was therefore found to be statistically significant.

Standard Error of the Estimate

It was required that the standard error of the estimate computed from the model be relatively low in comparison to the standard deviation of the first unit simulator cost data. The standard error of the estimate and standard deviation were:

Standard error -- $2,728,014.17

Standard deviation -- $9,055,186.76

The standard deviation was calculated from the cost data appearing in Table 2 and the standard error was calculated by the SPSS program for the four parameter model. The standard error of the estimate was relatively low in

comparison to the standard deviation of the cost data. The standard deviation was in fact more than three times greater than the standard error.

The distribution of the error terms for each data point was to depict a random scatter about the estimate of the dependent variable. This random scatter, if observed, would have indicated a normal distribution of the error terms. A normal distribution of error terms was necessary to permit the assumption of no bias in the estimate. Such a distribution of error terms was observed and is presented in Table 3. Additionally, Figure 1 depicts a plot of these residuals (error terms) as a percentage of actual cost values. Overall, the assumption of a normal distribution of error terms was valid and an unbiased estimate was inferred. Having developed a four parameter model that met the established statistical criteria, the remainder of the model validation process ensued.

External Test

It was intended that the developed model would be applied to a known system and its predictive ability assessed in that manner. Due to the limited amount of data however, there was no system available to which the model could be realistically applied. The three systems excluded from the data base for CER development (T-37, T-38 and ASUPT) were so dissimilar to the remaining systems that application of the model to those three was deemed inappropriate. Ultimate validation of the model through external test on similar

Table 3

Actual Versus Estimated Cost

System	Actual Adjusted Cost	Estimated Cost	Error Term	Error as a Percentage of Actual Cost
F-15	$9,018,876.88	$11,024,860.13	-$2,005,983.25	-22.2421
F-111A	10,350,947.00	8,349,192.75	2,001,754.25	19.3389
C-5A	12,766,956.63	12,969,534.00	-202,577.38	-1.5867
C-141	3,387,255.16	1,737,575.94	1,649,679.22	48.7025
A-7D	16,443,157.63	16,206,820.13	236,337.50	1.4373
HH-53	4,309,555.75	4,876,207.81	-566,651.06	-13.1487
FB-111A	13,363,636.38	11,624,611.00	1,739.025.38	13.0131
C-141A	2,801,107.56	5,652.696.25	-2,851,588.69	101.8022
		Sum:	$ - 4.03	

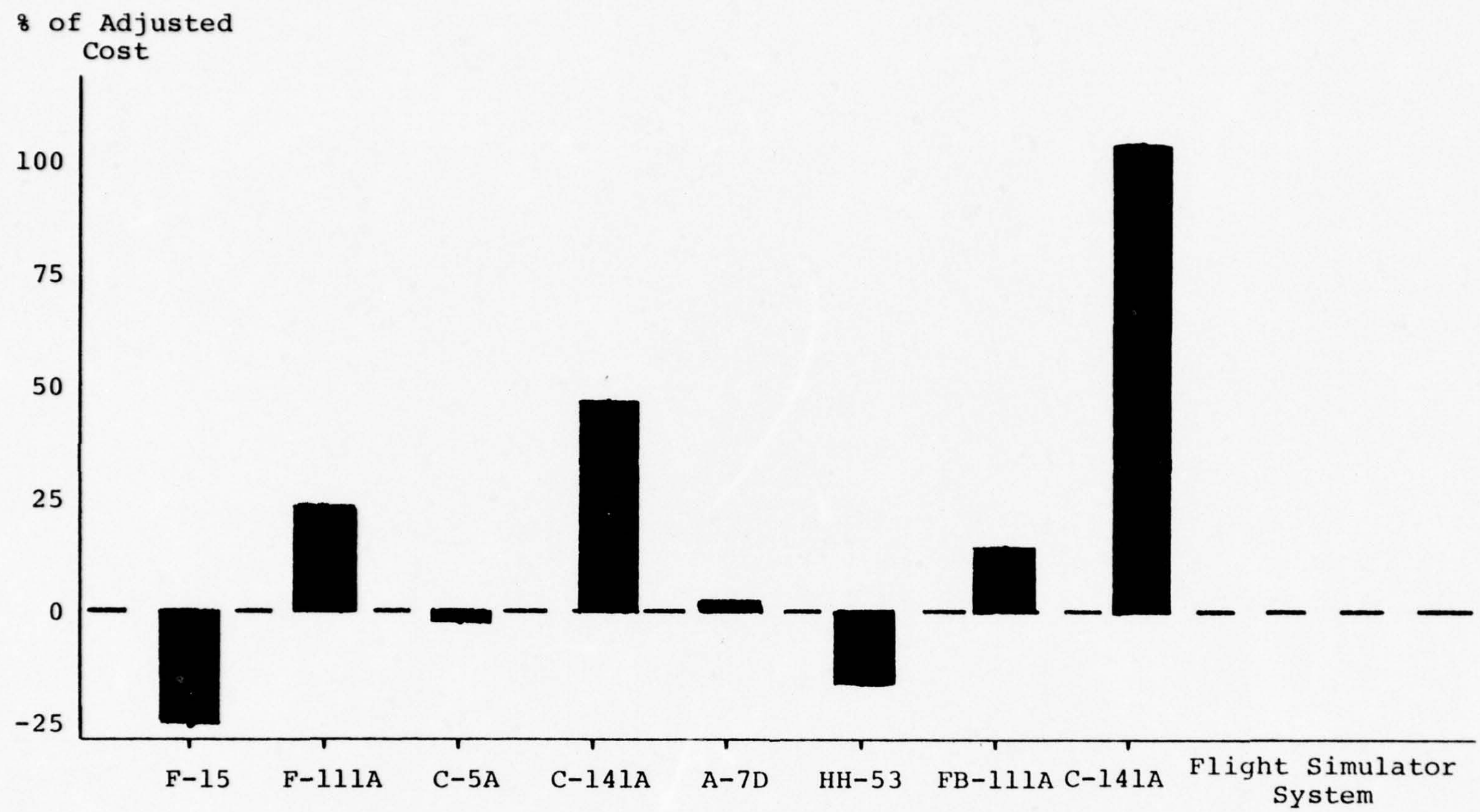

Figure 1. Residual as a Percentage of Adjusted Cost

flight simulator systems was left to those who might benefit from future use of the CER. It was noted however that all systems utilized in model development could be predicted by the model as to their actual costs plus or minus one standard error with only one exception.

Internal Test

The model was assessed as to its internal form. All variables were found to be logically related. That is, the coefficients of the independent variables were positive which indicated a direct relationship to cost. Statistical methodology was consistent throughout model development and all variables received equal treatment.

It was necessary to assume that the model error term, E, would be zero. This was, in effect, the case. The sum of the residual values (individual error terms) depicted in Table 3 was a minus $4.03. This value approximated zero quite satisfactorily considering the relative magnitudes of the residual values which contributed to the sum. The assumption of a zero value error term in the model was therefore supported.

CER/Parametric Model

The parametric model, or CER, developed is expressed below in equation form.

$$Y = -28{,}274{,}648.96 + 50.19X_1 + 369.26X_2 + 4{,}003{,}544.50X_3 + 35{,}232.25X_4 + E.$$

In this model the variables were:

Y - System first unit cost

X_1 - System cooling capabity in BTU/hour

X_2 - System weight in pounds

X_3 - System degrees of freedom for the motion platform

X_4 - System emergency procedures/malfunctions simulatable

E - Error term for the model

Cost, expressed in 1975 constant dollars, was the dependent variable of the above model. The independent variables appearing in the above model were those found to be statistically significant as predictors of cost. The error term, E, can be considered as having zero value.

SUMMARY

The CER was developed in accordance with the criteria established in Chapter 2. All criteria tests were passed by the CER with the exception of the external test criteria which could not feasibly be accomplished. Therefore, the research hypothesis was considered supported.

Chapter 5

MODEL USAGE AND APPLICATION

PREDICTIVE RANGE

The CER should be used to predict the first unit costs of flight simulator systems. Data required to utilize the CER includes known or predicted quantitative values for system cooling capacity, weight, motion platform degrees of freedom and emergency procedures/malfunctions simulatable. Extrapolation of data values and associated cost predictions beyond the values in the data base will necessarily cause those predictions to lose accuracy (12:56). The greater the extent of extrapolation beyond data parameters the greater will be the decrease in predictive accuracy of the CER.

To insure that the CER possesses a data base which will permit a realistic predictive range at any point in time, constant update of the CER is mandatory. Without update of the data base advancing technology will render the CER unuseable due to changing data parameters.

CER UPDATE AND MAINTENANCE

The Armed Services Procurement Manual (ASPM) encourages those activities which are the primary users of a CER to maintain responsibility for update and maintenance of the

CER (23:2D35). The CER which is the product of this research should be maintained by the primary flight simulator acquisition office in the U.S. Air Force, The Simulator Systems Program Office of the Aeronautical Systems Division, Air Force Systems Command. That office should have primary responsibility for continually guaranteeing CER data base currency as well as providing the continually updated CER to other offices which might benefit from its use.

CER maintenance and update require on-going data collection, continual reassessment of variables, search for more powerful variables, application of evolving statistical procedures and any other practices which might contribute to further CER refinement.

This research endeavored to conform to accepted CER development procedures. The decision rules which were enumerated in preceding chapters were consistent with both descriptive and inferential statistical procedures as well as established model development practices. It is noted however that no model perfectly describes reality except by chance. Utilizers of the CER this research has developed should be mindful of the inherent limitations of any statistical model. CER utilization should be but one element of a total cost estimation approach.

As a CER data base expands, the potential for CER refinement exists. A CER approaches predictive perfection only as the data base from which it is derived approaches the status of being collectively exhaustive.

Chapter 6

SUMMARY

ASSUMPTIONS

This research was predicated on important assumptions and limitations. They are consolidated and listed here for clarity.

1. The system for which the estimate is being made must be closely related to the systems used in the data base to define the relationship, and it must be assumed that the defined relationship still exists.
2. The data in the data base is accurate in its raw form, i.e., the data base was recorded in the contract files without error.
3. Separate simulator system characteristics are adequately homogeneous for aggregation into specific identifiable categories.
4. Acquisition difficulties encountered on the systems within the data base are characteristic of difficulties encountered in the total simulator acquisition experience.
5. Contractor profit on the various systems conforms to established DOD limits.
6. A linear model is most appropriate.

7. The expected value of the error term (E) is zero.

8. All of the error terms have a constant and equal variance.

9. The error terms are statistically independent.

10. The values of the error terms are normally distributed.

11. The number of observations exceeds the number of parameters to be estimated.

12. The values of the independent variables must be independent of each other.

LIMITATIONS

1. Accuracy of the cost estimate is limited by the fact that physical and performance characteristics do not represent all of the reasons for variance in cost.

2. When extrapolating beyond the values of data in the data base, confidence in the accuracy of the estimate decreases.

3. Predictive strength of the model is limited by the quantity and quality of the data base from which the model is developed.

RECOMMENDATIONS

The purpose of this research effort was to develop a parametric costing model, or CER, for flight simulator acquisition. Extensive research was conducted to acquire

the necessary background information as well as to describe the development methodology utilized. Statistical methods were explicitly detailed. Data utilized in model development was depicted as to source, type and salient features. Data collection methods were described. CER development was chronologically reported according to the established methodology. The CER, or parametric costing model, was presented along with pertinent comments concerning its utilization and applicability.

Ultimate validation of the CER is beyond the scope of this research. Data deficiency prevented a meaningful test of the CER's predictive accuracy within the context of this research. Future application of the CER to real world simulator acquisition processes will reveal the CER's worth. Even if the CER, in its present form, cannot be validated through application it should not be abandoned as a management tool. The CER should be updated and refined continually with emerging data so that its value to the simulator acquisition process is further enhanced.

It is recommended that the office which maintains this CER establish procedures for data collection and data update. This research effort was limited by both data availability and accessibility. To further refine this CER/model will require additional validated data and removal of outmoded data. Contract specifications for contractor provided data should include cost and physical/performance characteristics data similar to the data from which this CER

was developed. This method would guarantee continuing data availability and provide for update and refinement of the CER/model.

This initial research effort in the area of parametric cost estimation for flight simulators utilized aggregated descriptions of flight simulator cost, physical and performance characteristics. Future research is deemed feasible at a less aggregated level of description. That is, the CER developed herein may well be complemented by CER's for flight simulator subsystems and components. This possibility rests on the availability of data at the subsystem level. Overall, the necessity to collect and maintain these types of data has been shown to be critical to successful and expedient CER/model development.

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BIOGRAPHICAL SKETCHES OF THE AUTHORS

Captain Milton C. Ross graduated from the University of Colorado in 1968 with a Bachelor of Science Degree in Business Administration. He graduated from USAF Undergraduate Pilot Training in 1970 and has served as a Forward Air Controller in Southeast Asia and as an Instructor Pilot in Air Training Command. Following graduation from AFIT Captain Ross will be assigned as a Procurement Officer in the Simulator Systems Program Office (SPO) of the Aeronautical Systems Division at Wright-Patterson AFB, Ohio.

Captain Gerald L. Yarger graduated from Oklahoma State University in 1968 with a Bachelor of Science Degree in Agricultural Economics. He graduated from USAF Undergraduate Pilot Training in 1970 and has served as a Forward Air Controller in Southeast Asia and as an Instructor Pilot in Air Training Command. Following graduation from AFIT Captain Yarger will be assigned as a Supply Officer at Lajes Field, Azores.